

# NASA Marshall Impact Testing Facility Capabilities Applicable to Lunar Dust Work

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**Abstract.** The Impact Testing Facility at Marshall Space Flight Center has several guns that would be of use in studying impact phenomena with respect to lunar dust. These include both ballistic guns, using compressed gas and powder charges, and hypervelocity guns, either light gas guns or an exploding wire gun. In addition, a plasma drag accelerator expected to reach 20 km/s for small particles is under development. Velocity determination and impact event recording are done using ultra-high-speed cameras. Simulation analysis is also available using the SPHC hydrocode.

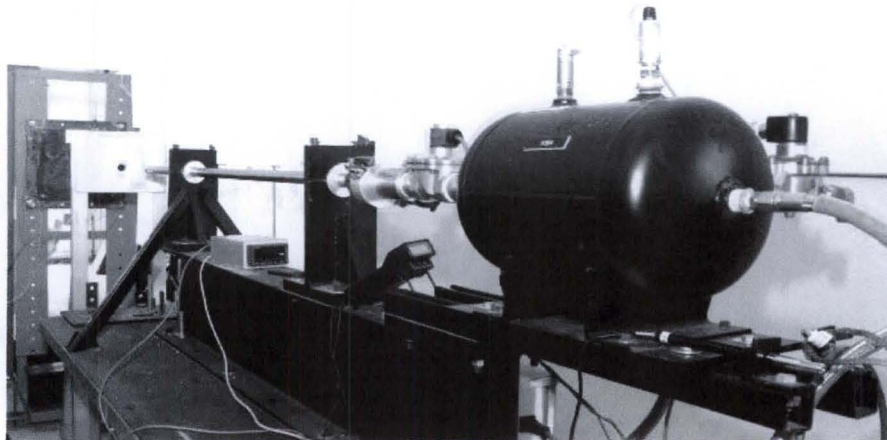
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## INTRODUCTION

The Impact Testing Facility (ITF) at Marshall Space Flight Center has several guns/accelerators that would be of use in studying impact phenomena associated with lunar dust. These phenomena include impacts by dust entrained in vehicle plumes onto vehicles or other structures; impacts by meteoroids onto materials composed of processed regolith, e.g., lunar concrete; and impacts by dust or other fragments cast out as ejecta from larger meteoroid impacts on the lunar surface. These impacts would occur at speeds from a few tens of m/s to tens of km/s, and Marshall's ITF guns can accelerate projectiles through a good portion of this velocity range. Ballistic velocities (tens to hundreds of m/s) are accessible to a pair of compressed gas guns, as well as a powder gun which can fire multiple projectiles. Hypervelocities (2 km/s and above) are reached using a pair of light gas guns. In addition, an exploding wire gun, currently under initial operational testing, is expected to allow shots across the ballistic-to-hypervelocity spectrum. We have also secured IRAD funding to develop a plasma accelerator which is expected to launch 50 to 250 micron projectiles at up to 20 km/s, providing access to the lower end of the meteoroid velocity range for the first time in a NASA facility. In addition to actual shot testing, hydrocode analysis is available to simulate impacts at speeds and onto targets not possible with our launchers. This code (SPHC) also allows examination of alternative structural geometries' response to impact, e.g., for shielding design.

## BALLISTIC IMPACT

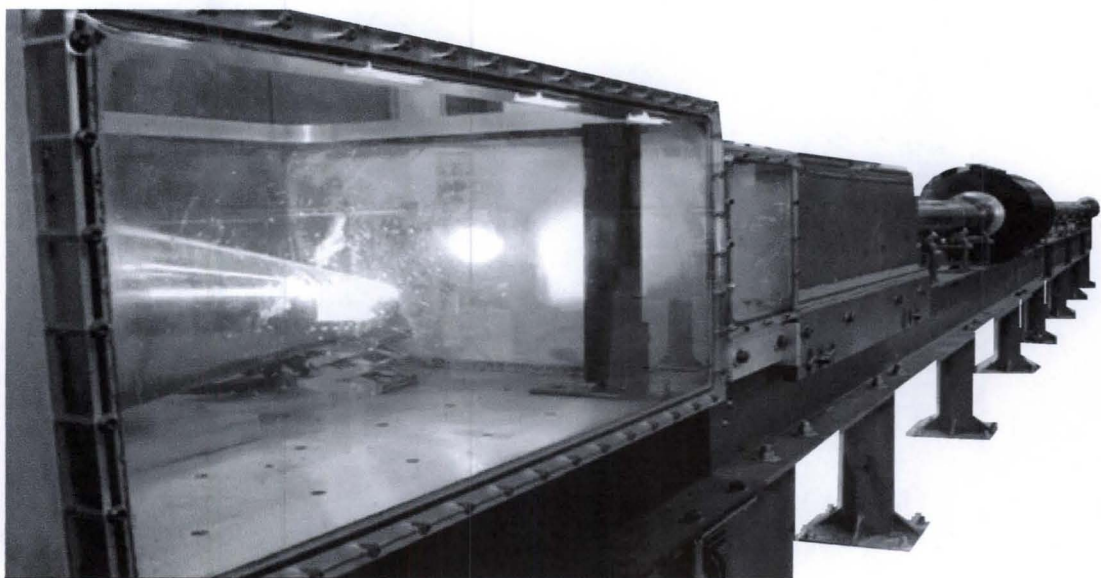
Ballistic impacts can be performed using both compressed gas and powder guns. The compressed gas guns, the Large Ballistic Gun (LBG) and Small Ballistic Gun (SBG) use helium as a propellant, and reside on an outdoor range. These guns can perform impacts at velocities up to 900 m/s. Currently the largest barrel has a 7.62 cm (3 in) inner diameter, but custom barrels can easily be made to accommodate a large range of projectile sizes and shapes. A high speed camera is used to capture the impact and measure velocity. In support of the shuttle program, the SBG (see Figure 1) has been used recently to examine launch debris impact scenarios, firing projectiles against thick steel plates. Types of simulated launch pad debris have included shuttle thermal protection system insulating foam,



**FIGURE 1.** Small Ballistic Gun.

inconel cylinders and spheres, and actual samples of launch pad rust. In the near future, hail impacts on other targets, such as vehicle windows, will be simulated using water ice spheres. Since these guns are outdoors, very large target items, such as full-scale components, can be accommodated.

The single/multi-particle Environmental Impact Gun (EIG) is a powder gun that can accelerate particles between 0.01 – 50.0 mm to velocities up to 2000 m/s. This system was historically used to simulate rain using nylon beads, but it is not limited to any specific type of projectile. Potential applications include studies of dust and sand impact erosion, rocket motor ejecta, and other small particle impact phenomena. These uses pertain directly to lunar surface environment work, where meteoroid impact ejecta and plume-entrained dust will be a factor. Meteoroid impact ejecta is expected to be a significant component of the overall particulate environment. This ejecta travels at speeds accessible to the EIG, rather than the hypervelocities of the primary meteoroid impactors. The EIG uses high speed cameras to capture impact events. The current target chamber is approximately 20 x 13 x 28 inches, but larger samples could be handled by constructing a new chamber, for which there is plenty of room in the building.



**Figure 2.** Single/multi-particle Environmental Impact Gun.



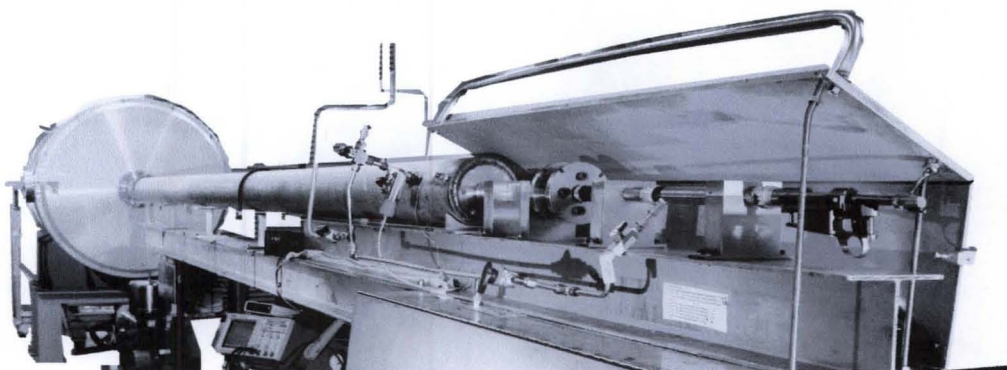
## HYPERVELOCITY IMPACT

Meteoroid impacts are a serious concern for all spacecraft. While orbital debris impacts are also of concern for vehicles in orbit near the Earth, debris (man-made objects and fragments thereof) is less of an issue near the Moon. Marshall's Light Gas Gun (LGG) and Micro-Light Gas Gun (MLGG) have been used in the past to study debris impact effects for the ISS program. An Exploding Wire Gun (EWG) is currently undergoing operational testing. This gun is expected to span the speed range from many tens of m/s to several km/s. A fourth hypergun, a Plasma Accelerator (PA), is now under development. This accelerator should be able to launch very small particles at up to 20 km/s.

The MLGG (see Figure 3) is capable of accelerating small particles (0.4 to 1.0 mm dia.) to velocities of 3 to 7 km/s. The test chamber can accept targets on the order of 1 m in diameter. Currently, the average projectile velocity for each test is measured using photodiodes, but this method will soon be replaced by ultra-high-speed photographic technology. An example MLGG impact test result is shown in Figure 4, which shows the damage produced by an aluminum sphere 1 mm in diameter impacting a 5-cm cube of sulfur concrete at 5.85 km/s. This test sample simulates a candidate building material using lunar resources: lunar regolith and products produced by processing the regolith. The test sample was made of JSC-1 Lunar Regolith Simulant bound with molten sulfur and allowed to cool.

To examine effects of larger projectiles, the LGG can fire spheres or cylinders in the diameter range 2 to 19 mm at speeds of 2.5 to 7.5 km/s. This gun can accommodate targets up to 3 m diameter and about 6 m long. For the LGG, projectile velocity is also measured by photodiodes, but, as with the MLGG, soon ultra-high-speed cameras will be employed for this purpose.

The Exploding Wire Gun is designed to accelerate 0.4 to 4.0 mm particles to velocities from tens of m/s to 7 – 8 km/s. This system is quite versatile, as it can also heat samples to ~3800 K prior to impact. The EWG will also use high speed cameras to record impacts and measure velocities. Note that this gun can launch projectiles at speeds characteristic of meteoroid impact ejecta and engine-plume-entrained surface particles. In this respect it represents a backup capability to that of the EIG. The EWG is currently undergoing initial operational testing and calibration.



**FIGURE 3.** Micro Light Gas Gun.

The Plasma Accelerator will be constructed using parts developed for an advanced propulsion project that has been discontinued. The PA will employ a coaxial plasma acceleration cylinder leading into a compression coil, immediately after which projectile samples will be exposed to the plasma drag. Such a device has been built at the Technical University of Munich, and has succeeded in accelerating small particles to 20 km/s (Egenbergs, Jex, and Shriver, 1975). Because this velocity, which is characteristic of the lower end of the meteoroid velocity spectrum, has been previously inaccessible to NASA facilities, this will be our first opportunity to develop impact data with controls on projectile size, mass, and composition.





**Figure 4.** MLGG Test Impact on “Lunar Regolith Sulfur Concrete” Block.

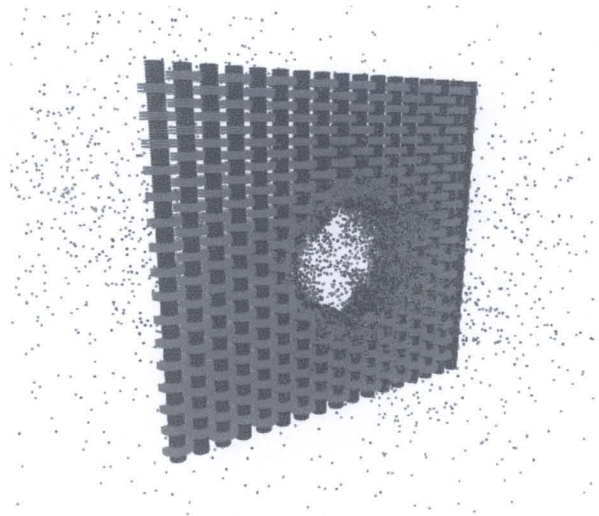
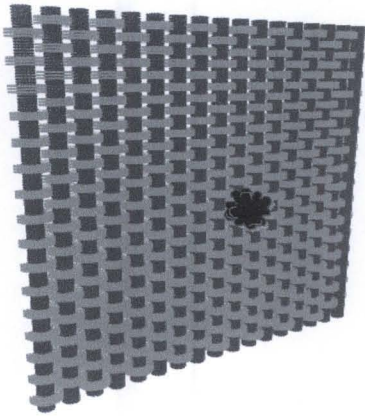
We look forward to experiments involving acceleration of meteoroid simulants, e.g., olivine spheres in the 50 to 250  $\mu\text{m}$  size range, against shield materials, wiring harnesses, windows, etc. The results will be important in themselves, and will provide experimental benchmarks to validate the results of ultra hypervelocity impact simulations, as discussed below.

## **IMPACT SIMULATION ANALYSIS**

The Impact Testing Facility has impact simulation analysis capability using the SPHC<sup>TM</sup> Smooth Particle Hydrodynamics code (Stellingwerf, 2006). This code aids in understanding how specific materials or shielding structures will behave when impacted at higher velocities than may be seen in the laboratory or range, but which may be encountered in space.

SPHC can handle 1-, 2-, or 3-D versions of a problem. It accommodates many materials for which a specified set of properties are known, using any of several equations of state, and several material strength and fracture models. SPHC has flexible geometric modeling capabilities, so a variety of articles can be simulated, including complex shapes, such as bullets, porous items, and multilayered/multimaterial objects. Impacts at any speed below about 80 km/s can be simulated, with items initially at temperatures, densities, porosities, and internal pressures selected by the user. Complex objects can be built up from simpler constructs, duplicated, and manipulated as desired in the simulation space.

Figure 5 shows an example simulation of a woven fabric impacted by a meteoroid. The vertical fibers are Kevlar<sup>TM</sup> 49, the horizontal fibers are Kevlar<sup>TM</sup> 29, and the meteoroid is a “bumpy sphere” of silica glass. The impact speed is 24.5 km/s, the projectile diameter is 375 microns, and the fabric panel measures approximately 6.25 x 6.125 mm laterally and 0.4 mm thick. At this speed the fabric at the impact site and the meteoroid are vaporized, creating a hole about 2.2 mm in diameter. Impact debris and ejecta are primarily vapor, although some solid fragments and liquid droplets are also present.



**Figure 5.** Impact of a Meteoroid on a Kevlar <sup>TM</sup> Woven Panel, Simulated with SPHC.

## CONCLUSION

In summary, MSFC's ITF offers impact testing capabilities that may be applicable to lunar environmental work, including: two compressed helium guns, a multi-particle powder gun, two light gas guns, an exploding wire gun, and, in development, a plasma accelerator "dust gun." In addition, simulation analysis is available using the SPHC hydrocode. These capabilities can be brought to bear on practical lunar dust environment problems.

## REFERENCES

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